



LAWRENCE  
LIVERMORE  
NATIONAL  
LABORATORY

# Reducing the Consequences of a Nuclear Detonation; Recent Research and Guidance

B. R. Buddemeier

April 14, 2010

Reducing the Consequences of a Nuclear Detonation; Recent Research and Guidance

## **Disclaimer**

---

This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.

# Recent Research in Reducing the Consequences of a Nuclear Detonation

---

*By Brooke Buddemeier, Lawrence Livermore National Laboratory*

## **ABSTRACT**

*“One nuclear weapon exploded in one city—be it New York or Moscow, Islamabad or Mumbai, Tokyo or Tel Aviv, Paris or Prague—could kill hundreds of thousands of people. And no matter where it happens, there is no end to what the consequences might be for our global safety, our security, our society, our economy, to our ultimate survival.”*

-- President Barack H. Obama, April 5, 2009

The federal government continues to put significant resources into non-proliferation of nuclear weapon technology and materials, ensuring the security of existing stockpiles, and detecting potential threats as they move overseas, through our borders, and within our homeland. However, a terrorist attack using a nuclear weapon in the coming decades remains a distinct possibility and prudence requires we consider nuclear detonation response planning to ensure a nation that is resilient to all potential terrorist attacks and natural disasters.

Analysis by Department of Energy (DOE) National Laboratories and other technical organizations have updated our cold war understanding of potential impacts of a ground level, low yield nuclear detonation and the impact response planning can have on national resiliency. Federal response planning continues to make improvements in coordination and recommending protective actions, but much work remains. The most critical life-saving activity depends on actions taken in the first few minutes and hours of an event. Recent response planning activities have revealed that a significant number of lives can be saved by a few simple actions taken by the public and local response agencies in preparation for, and immediately after, a nuclear detonation.

A key finding is that early, adequate shelter followed by informed, delayed evacuation can save those in potential fallout areas from life threatening exposures. “Adequate shelter” is no longer the fortified and specialized “fallout shelter” of the cold war, but rather buildings (or locations within buildings) that are ubiquitous in urban areas. Also the suggested time spent in the shelters is measured in hours, not days or weeks.

A small amount of awareness and regional response planning can potentially save hundreds of thousands of lives by informing appropriate post detonation actions.

## Roentgens, rads, and rem: Units of Radiation Exposure

This document uses units familiar to American audiences and American emergency responders. For those unfamiliar with these units, a brief description follows.

- **Roentgen (R):** A unit of gamma or x-ray exposure in air. It is the primary standard of measurement used in the emergency-responder community in the US. 1,000 milli-roentgen (mR) = 1 Roentgen (R).
- **Roentgen per hour (R/h):** A unit used to express gamma or x-ray exposure in air per unit of time (exposure rate) and the unit most commonly seen on radiation-detection equipment used by responders.
- **rad:** A unit expressing the absorbed dose of ionizing radiation. Absorbed dose is the energy deposited per unit mass of matter. The units of rad and gray are the units in two different systems for expressing absorbed dose. (International unit conversion: 1 rad = 0.01 gray [Gy]; 1 Gy = 100 rad.)
- **rem:** A unit of absorbed dose that accounts for the relative biological effectiveness (RBE) of ionizing radiations in tissue (also called equivalent dose). Not all radiation produces the same biological effect, even for the same amount of absorbed dose; rem relates the absorbed dose in human tissue to the effective biological damage of the radiation. (International unit conversion: 1 rem = 0.01 Sieverts [Sv]; 1 Sv = 100 rem.)

For the purpose of this guidance, 1 R (exposure in air)  $\approx$  1 rad (absorbed dose)  $\approx$  1 rem (whole-body dose). Whole-body doses are calculated for the middle of the body (1.5 m off the ground and 70% of the body-surface exposure), also referred to as the "midline deep dose."

## INTRODUCTION

Although response to nuclear terrorism has been a key part of national preparedness since the formation of the Department of Homeland Security<sup>a</sup>, little actual research had been performed to improve the understanding of potential effects and mitigation strategies specific to a low yield, ground level nuclear detonation until recently. An effective response involves managing large-scale incident response, mass casualty, mass evacuation, and mass decontamination issues. Preparedness planning activities based on this scenario provided difficult challenges in time critical decision making and managing a large number of casualties within the hazard area. Perhaps even more challenging is the need to coordinate a large scale response across multiple jurisdictions and effectively responding with limited infrastructure and resources.

In 2007, Congress expressed concern that cities have little guidance available to them to better prepare their populations to react in the critical moments shortly after a nuclear terrorism event and directed the Department of Homeland Security (DHS) Office of Health Affairs (OHA) to address this issue through engagement of the National Academies' Institute of Medicine, the Homeland Security Institute, DOE National Laboratories, and State and Local Response organizations<sup>1</sup>. This activity continues today through the Federal Emergency Management Agency (FEMA) as part of a coordinated federal effort for improving nuclear detonation response planning.

At the start of the OHA effort, there appeared to be a lack of scientific consensus on the appropriate actions to take after a nuclear detonation. For example, the recommendations of the Department of Homeland Security's *Ready.gov*, which are consistent with the recommendations of the National Academy of Sciences<sup>2</sup>, were recently criticized by the Federation of American Scientists<sup>3</sup> because of conflicting recommendations with a RAND study<sup>4 5</sup>.

Moreover, the existing federal protective action guidance<sup>6</sup> focused on avoiding relatively low level exposures to decrease the possibility of cancer from an accidental transportation or nuclear power plant release and was inappropriate for the key lifesaving decisions in the immediate aftermath of a nuclear detonation.. The Cold War civil defense program can help with some insights and advice, but many of the paradigms no longer apply. For example, the concept of a fallout shelter worked well with a few minutes warning of incoming missiles but its applicability is less clear for an attack that occurs without any notice.

During the OHA activity, observations from state and local stakeholder workshops indicated that few, if any, communities have a coordinated regional response plan for responding to the aftermath of a low yield (< 10 kiloton) nuclear detonation. The results of these workshops highlighted a general lack of understanding of the response needs and

---

<sup>a</sup> Scenario #1 of the 15 Department of Homeland Security national planning scenarios is an improvised nuclear detonation in the national capital region.

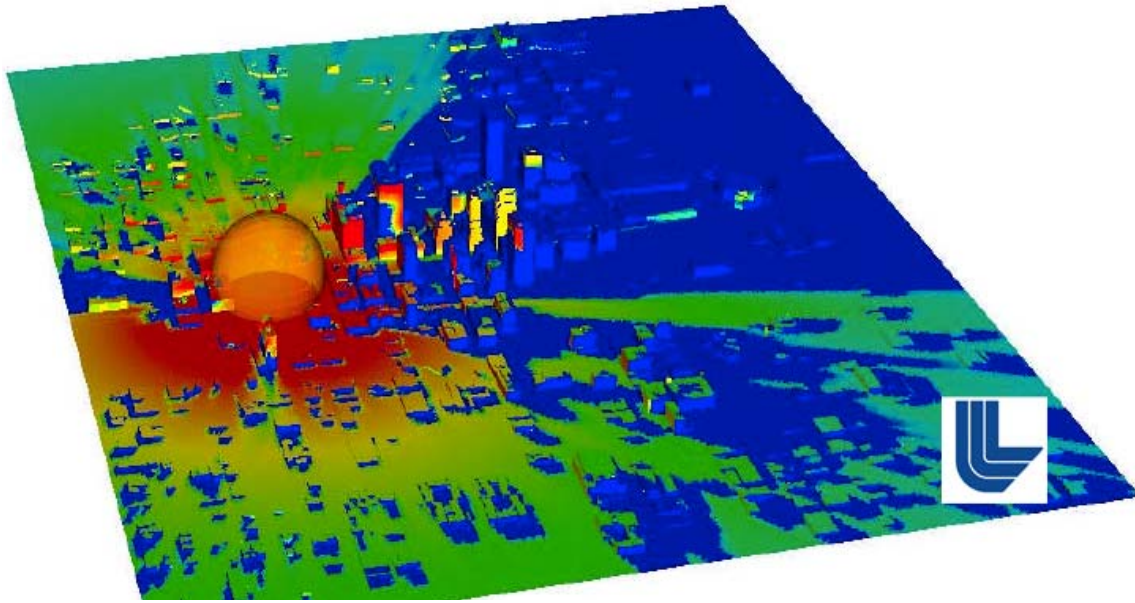
uncertainty of the federal, state, and local roles and responsibilities. At an Institute of Medicine's workshop on IND medical response planning, Chicago responder Joseph Newton comment on responding to an IND was<sup>7</sup> ***"We don't know what perfect looks like."***

## **RECENT RESEARCH**

To resolve the possible conflicts in the technical community and create a coordination point for research activities, DHS formed the IND Modeling and Analysis Coordination Working Group (MACWG). This working group is comprised of national laboratories, technical organizations, and federal agencies researching IND effects and response strategies. The purpose of the MACWG was to: (1) establish scientific consensus (where possible) on the IND effects and issues, (2) bound uncertainty and identify unknowns, and (3) resolve conflicts in recommended IND response actions.

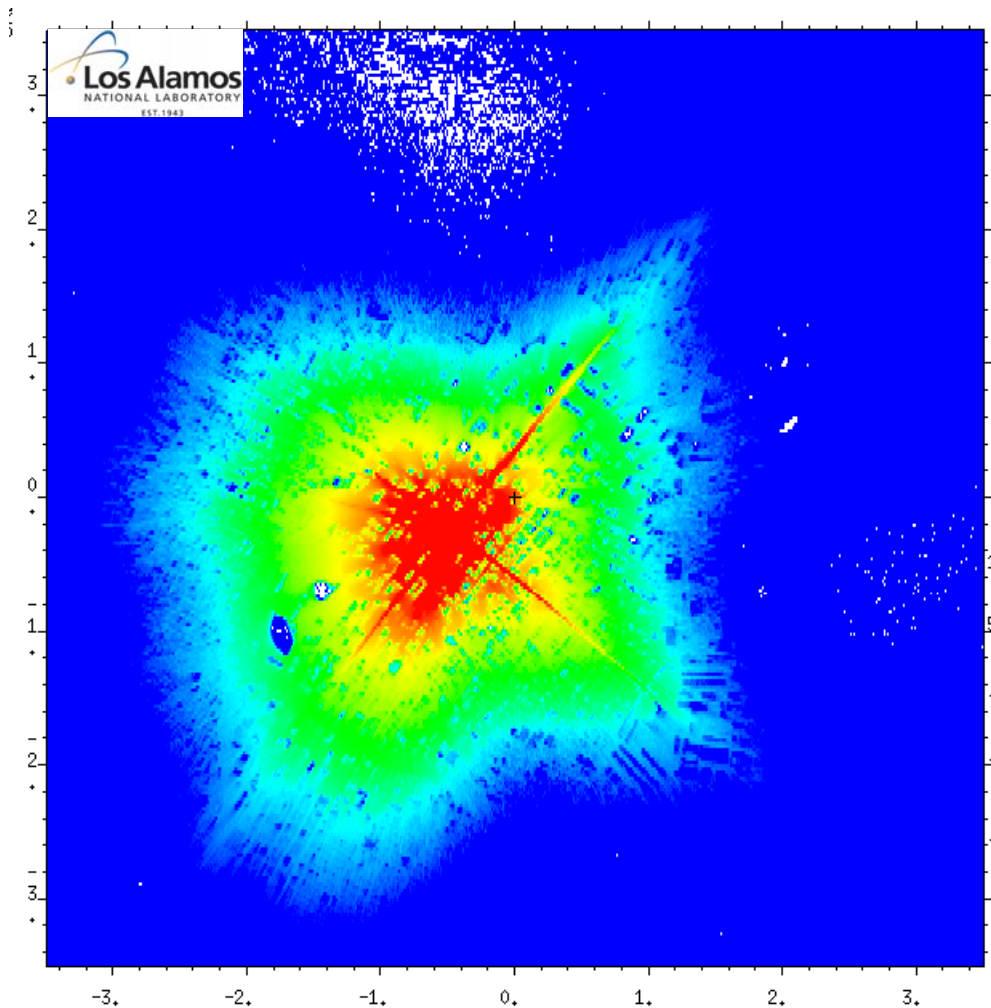
As directed by Congress, DHS Office of Health Affairs has coordinated an extensive effort involving the effects modeling of 0.1, 1.0, and 10 kiloton nuclear yields in New York City, Washington DC, Chicago, Houston, San Francisco, and Los Angeles; workshops in state and local communities across the nation as well as the National Academies; focus group testing of public messaging; and coordination with key federal agencies, national laboratories and technical organizations who have unique capabilities and knowledge regarding nuclear effects and emergency response.

The results of recent modeling indicate the modern urban environment can greatly mitigate some of the effects of a low yield nuclear detonation. For example, the potential number of thermal burns that occur from the heat of the initial explosion can be greatly reduced by the urban environment as it blocks this primarily line of sight phenomenon. A Lawrence Livermore National Laboratory technical report<sup>8</sup> demonstrates this visually with Figure 1 showing how buildings shadow areas that protect the outdoor population from significant thermal exposure (areas of low exposure are shown in green and blue).



**Figure 1: Integrated thermal flux from a 10kt ground level nuclear detonation in a small US city.**

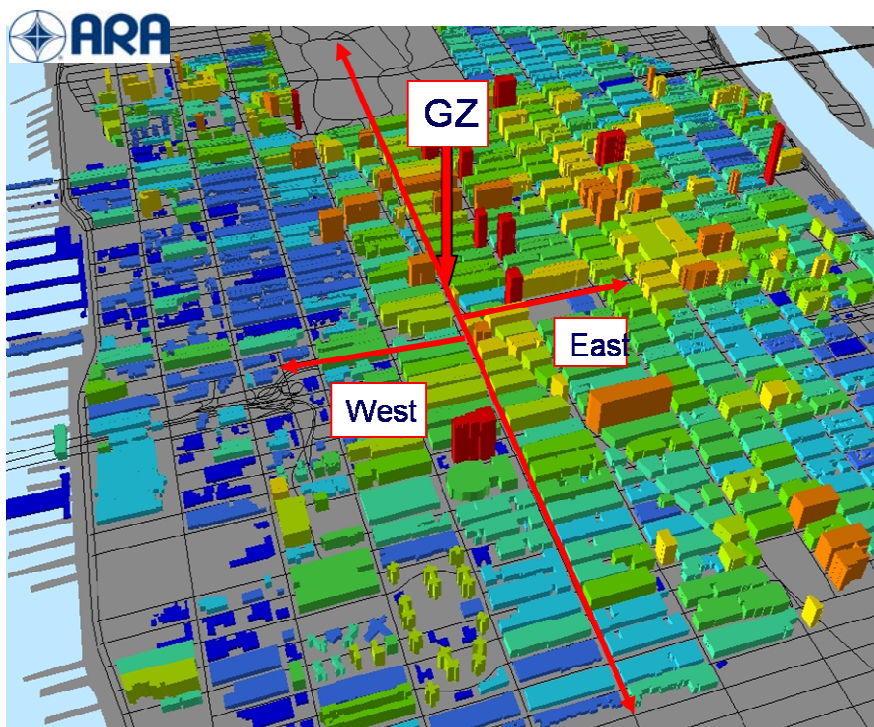
Work done at Applied Research Associates and Los Alamos National Laboratory have modeled a similar reduction in effect for the initial radiation that is produced in the first minute of the nuclear detonation.



**Figure 2: Initial gamma radiation from a nuclear detonation in the urban environment<sup>b</sup>**

Again, the green and blue areas on the Los Alamos graphic represent areas of low, survivable exposure levels. The work at Applied Research Associates converted an entire cityscape into a modeling environment to perform detailed radiation transport studies. Like the thermal analysis, these studies indicate that the ambient radiation levels from a low yield, ground level nuclear detonation may be significantly reduced. For example, the unobstructed range to a potentially lethal radiation exposure of 400 rads (cGy) is about 1,200 yards, however initial results of the work by Applied Research Associates indicates that the range to this effect might be reduced by 1/3 or more down to 600 – 800 yards from the detonation in built up areas. The graphic below indicates the types of detailed modeling being conducted.

<sup>b</sup> Image courtesy of JT Goorley, the ASC's Nuclear Weapon Effects for Urban Consequences, Los Alamos National Laboratory, LA-UR 09-00703 and LA-UR-10-01029. For more information contact Tim Goorley; jgoorley@lanl.gov



**Figure 3: Applied Research Associates model used for radiation transport studies<sup>c</sup>**

Primary among prompt effects is blast. A 10kt explosion is equivalent to ~5,000 truck bombs like the one used to destroy the Murrah building in the 1995 Oklahoma City bombing<sup>9</sup>. Blast will severely damage or destroy most buildings within ½ mile of the detonation location and it is unlikely that the population in this area would survive. From a ½ mile to about a mile out, survival will mostly likely depend on the type of structure a person was in when the blast occurred. Even at a mile, the blast wave will have enough energy to overturn some cars and severely damage some light structures.

Updating our cold war understanding of blast damage to a modern city is another area of important, nescient research. For example, a key long range prompt effect injury concern is glass breakage. A significant number of victims from Nagasaki arriving at field hospitals exhibited glass breakage injuries<sup>10</sup>, and most of the injuries outside of the Murrah building in the 1995 Oklahoma City bombing were caused by this phenomenon<sup>11</sup>. Extrapolating from more recent work on conventional explosives<sup>12</sup>, a 10kt explosion could break windows over 8 miles away. Although improved building codes since the cold war may result in better building survival, the larger window sizes in modern buildings creates a higher likelihood of window breakage and potential injury for those near the windows.

Injury from glass breakage has not previously been well modeled as it was generally considered “not of military significance” for cold war planners. Hiroshima and Nagasaki

<sup>c</sup> Image courtesy of Applied Research Associates, for more information contact Kyle Millage; [kmillage@ara.com](mailto:kmillage@ara.com)

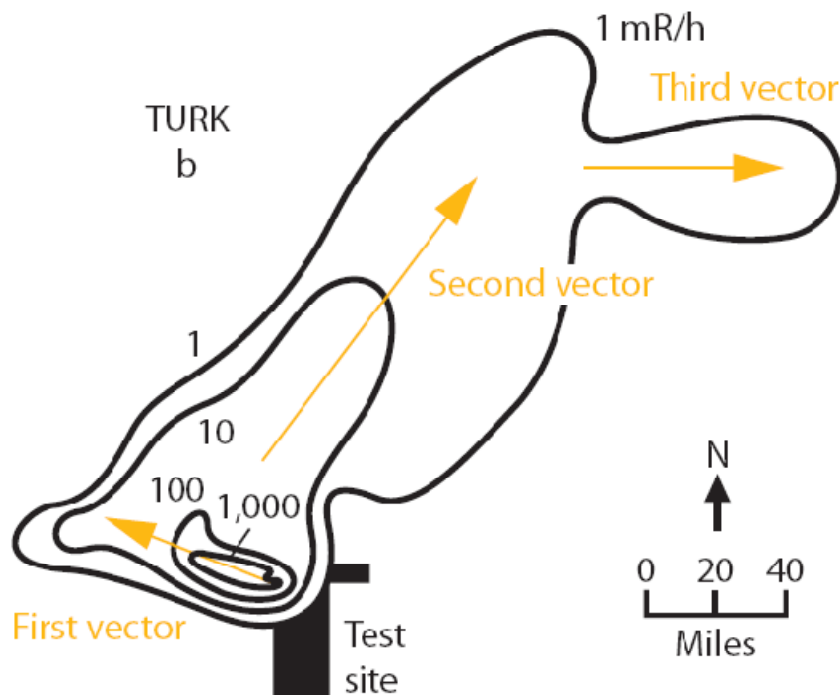
demonstrated that the area of glass breakage is nearly 16 times greater than the area of significant structural damage<sup>13</sup>. NATO medical response planning documents<sup>14</sup> for nuclear detonations state that "... missile injuries will predominate. About half of the patients seen will have wounds of their extremities. The thorax, abdomen, and head will be involved about equally." The American Academy of Ophthalmology noted "*Most injuries among survivors of bombings have been shown to result from secondary effects of the blast by flying and falling glass, building material, and other debris. Despite the relative small surface area exposed, ocular injury is a frequent cause of morbidity in terrorist blast victims.*"<sup>15</sup>

In addition to prompt effects which radiate outward from the detonation site, a nuclear detonation can also produce nuclear "fallout," which is generated when the dust and debris excavated by the explosion are combined with radioactive fission products produced in the nuclear explosion and drawn upward by the heat of the event. This cloud rapidly climbs through the atmosphere, potentially up to 5 miles high for a 10kT based on our nuclear test data, forming a "mushroom cloud" under ideal conditions from which highly radioactive particles drop back down to earth as it cools. It is important to note that Hiroshima and Nagasaki did not have significant fallout because the detonations occurred at altitude 1,900 and 1,500 ft, respectively, and the fission products did not have the opportunity to mix with the excavated earth.

In the absence of real, complex weather information, fallout modeling typically used the cigar shaped Gaussian fallout pattern. Although this pattern can occur, it is not a good planning assumption as more complex fallout patterns are more challenging and also frequently occur, particularly in coastal areas. Fortunately, higher-fidelity atmospheric dispersion models are now available that take into account the complex wind profiles typically found in our atmosphere and that provide a significantly more realistic evaluation of how hazardous material will move in time and space.

The fallout distribution used in this analysis was generated by the National Atmospheric Release Advisory Center (NARAC) at Lawrence Livermore National Laboratory (LLNL), which is currently the primary operations center for the Interagency Modeling and Atmospheric Assessment Center (IMAAC). This analysis used an advanced suite of 3-D meteorology and plume/fallout models that account for complex meteorology and terrain effects.

Realistic, complex weather patterns result in irregular shaped areas of ground contamination. Even nuclear tests performed at the Nevada Test Site, when shot times could be selected for favorable weather conditions, often resulted in fallout patterns that were unlike the "cigar" shaped Gaussian plots that are commonly used for response planning (Figure 7-need to update figure #).

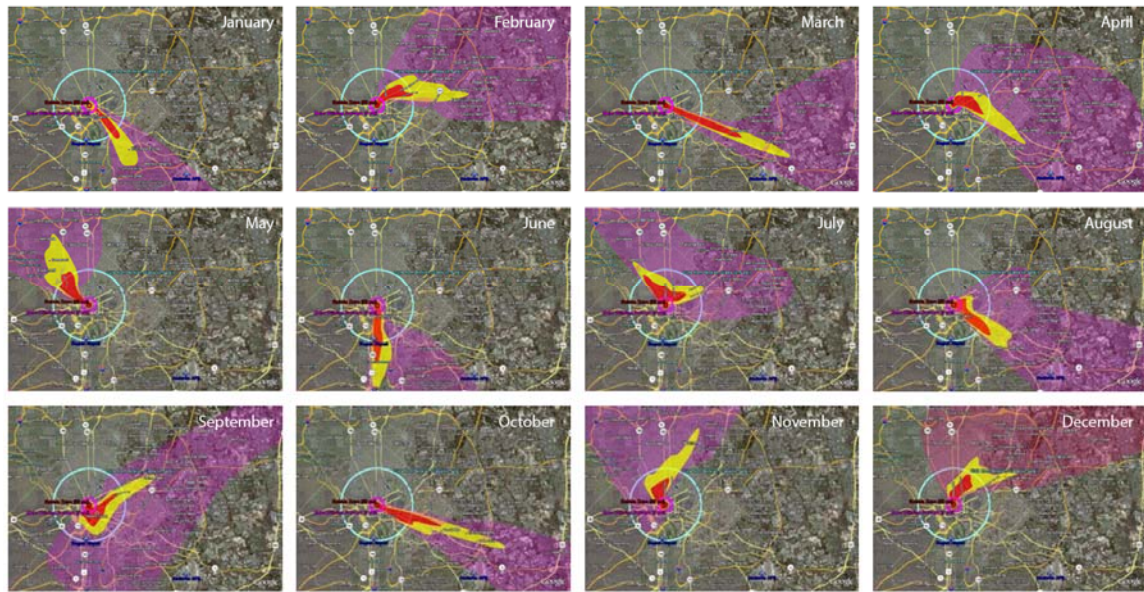


**Figure 7. Early fallout dose-rate contours from the TURK test at the Nevada Test Site (Ref. 31, Figure 9.58b).**

The 12 fallout patterns in [Table 3](#) below represent a sample of how weather affects fallout patterns over the Washington, DC area. The weather data was based on detailed atmospheric soundings at nearby weather stations. An analysis was performed to determine potential fallout patterns using the weather from the 15th of each month in 2006. A noon detonation time was arbitrarily selected.

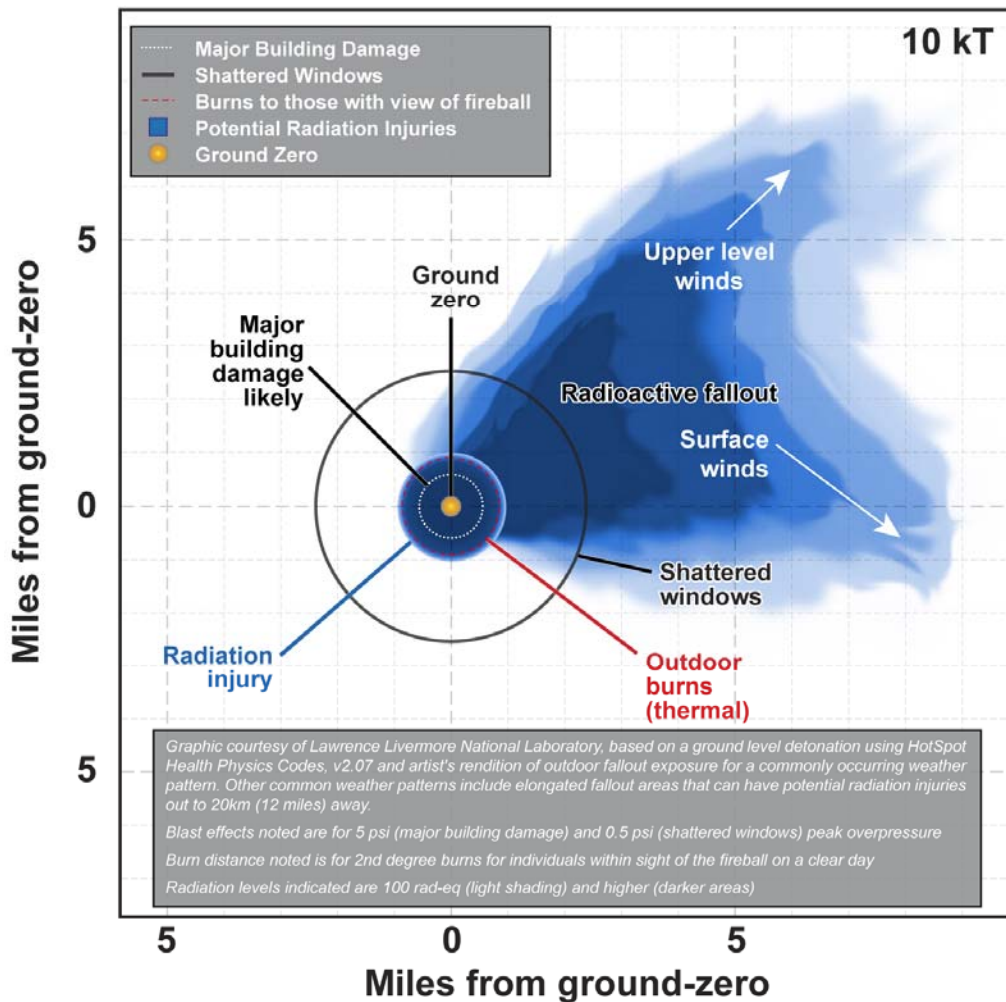
In the images below, the inner, magenta circle is the range where major building damage would be expected, and the outer, blue circle is the range where glass is being broken with enough force to cause injury. The color coding of the fallout areas are 300 rem (red), 100 rem (yellow), and 1 rem (light magenta) for a two-hour outdoor exposure. These figures are not meant to portray all possible fallout patterns or the full statistical variance for the possible fallout in the Washington, DC area. They do, however, illustrate how complex and variable fallout patterns can be.

Table 3. Example of 12 different fallout patterns for Washington, DC.



Basing response plans on the expectation of a “cigar shaped” Gaussian fallout pattern creates the false impression that fallout is constrained to a symmetric, easily delineated area. This provides an unrealistic expectation that the fallout area will be quickly and easily traversed and that the impacted population in the fallout area will have perfect situational awareness of what areas have been contaminated by fallout. This has presumably contributed to the “evacuate immediately” guidance<sup>3,4</sup> that can result in higher exposures when used on common, non-Gaussian fallout patterns, as it often places people outdoors and in harm’s way when the radiation levels are highest. The difficulty and hazard of implementing an immediate, lateral evacuation tactic is readily apparent for someone north of the detonation location on July 15, 2006 (in Table 3 above) trying to evacuate “perpendicular” to the bifurcated plume.

An artist’s rendition of the key prompt fallout combined issues can be visualized in Figure 4. The prompt and thermal exposure ranges are for an unobstructed view of the fireball and, as noted above, these effects circles should be considered the likely maximum range and actual results will often be significantly attenuated by intervening buildings. The fallout pattern depicted demonstrates one of the possible ground contamination patterns and potential exposures in the shaded areas to northeast and east of ground zero. Actual exposures will depend on the length of time spent in the fallout area and the quality of the shelter.



**Figure 4: Artist rendition of key nuclear detonation effects (LLNL)**

Unlike prompt effects which can occur too rapidly to easily avoid<sup>d</sup>, fallout health impacts can be mitigated by leaving the area before fallout arrives or by sheltering from it. Although some fraction of ionizing radiation can penetrate buildings, the 1) shielding offered by walls and 2) distance from outdoor fallout particles can easily reduce exposures by a factor of ten or more for many common urban buildings.

The quality of shelter is described by the protection factor (PF), which is equal to the ratio of outside dose rate divided by inside dose rate. As with the SPF of sunscreen, the higher the PF, the lower the exposure that a sheltered person receives compared to an

<sup>d</sup> Note that the Civil Defense program advice of “Duck and Cover” can provide protection from prompt effects of flying glass and the thermal pulse; however it requires reacting properly to the bright flash within the first few seconds.

unsheltered person in the same area. Figure 4 demonstrates some example PF estimates based on evaluations conducted circa 1960 on typical structures during that era.

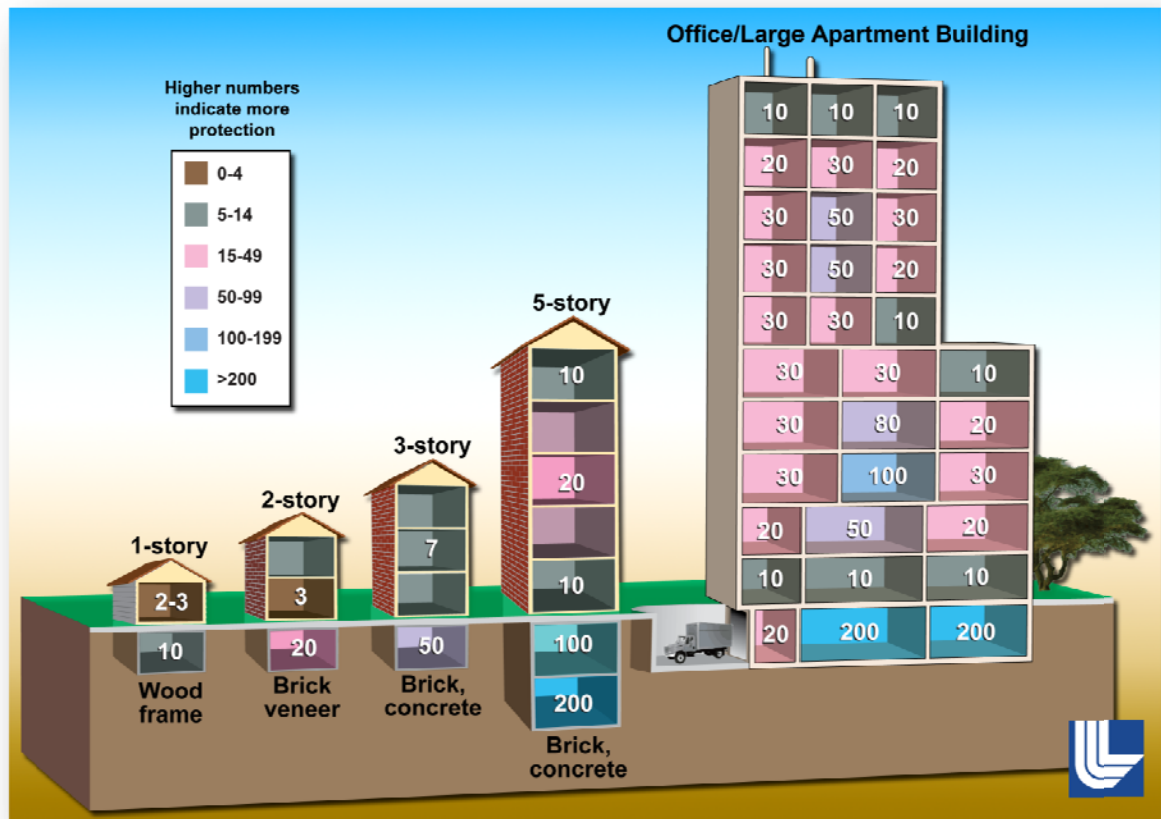
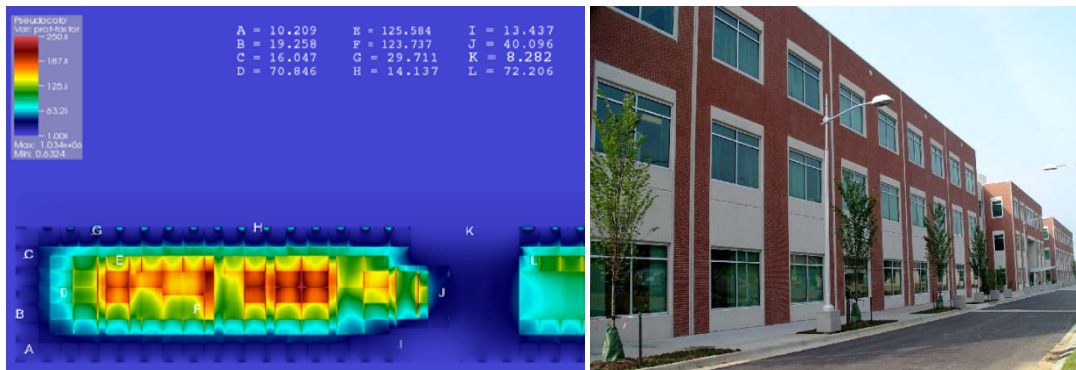


Figure 5: Typical Protection Factors (PF) estimated during the cold war (LLNL)

Efforts are underway at several National Laboratories and Applied Research Associates to use advanced modeling capabilities to update our understanding of the level of protection that modern building can provide from fallout radiation. The example below is from Oak Ridge National Laboratory's analysis of a modern 3 story office building<sup>16</sup> where almost all of the first floor locations pictured had a protection factor of 10, and many were above 100.



**Figure 6: Protection can vary depending on location in building and type of building, images courtesy of Oak Ridge National Laboratory**

Studies performed by Sandia National Laboratories<sup>17 18 19</sup> evaluate the effectiveness of various shelter/evacuation studies. In the Los Angeles scenario analyzed, even a moderate shelter with a PF of 10 reduced the number of people who received a significant exposure of 100rem or more from ~285,000 people down to ~45,000 people. Higher PF shelters, which are common in the urban environment, can reduce the number of exposed people even further.

The Sandia National Laboratories work also analyzed various evacuation strategies. As can be seen in Figure 7, the dose the evacuee receives leaving reference point #1 is dependant of the selected evacuation route. The heights of the path in the image represent the radiation levels (or dose rate) that the evacuee is exposed to during their journey.

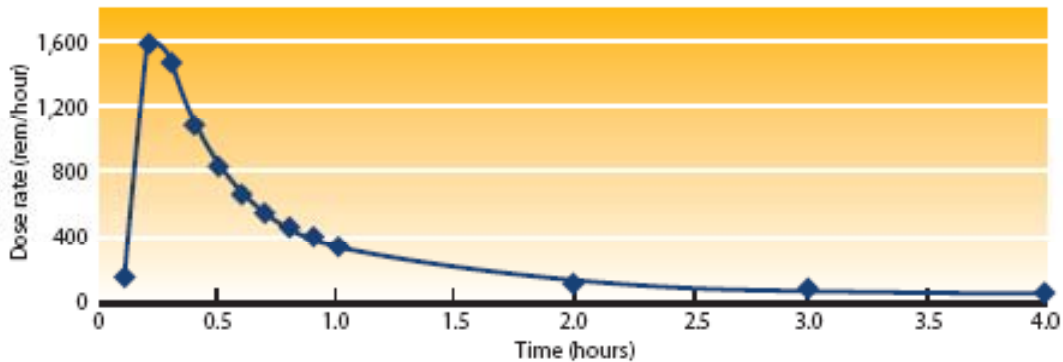


**Figure 7: Sandia National Laboratories Analysis of Evacuation Strategies, image courtesy of Sandia National Laboratories.**

Unfortunately, without additional outside information, evacuees would likely not know which evacuation route would provide the lowest exposure. Within a few miles of the detonation, dust and debris created by the blast wave would likely cloud the air and obscure vision. Once the dust settles and the fallout cloud has passed downwind, there may be little visual evidence to provide an indication of fallout hazard areas as sheltered populations emerge.

The hazard from fallout is not from breathing the particles, but rather due to exposure to the ionizing radiation given off after the fallout particles have settled on the ground and building roofs.<sup>20 21 22 23 24</sup> Radiation levels from these particles will drop off quickly, with most (~55%) of the potential radiation exposure occurring within the first hour after detonation and ~80% occurring within the first day. Figure 8 is from a LLNL analysis<sup>25</sup> that demonstrates this rapid decay of potential dose rates 1.6 miles (2.6 km) downwind of a 10kt. Although it is highly dependent on weather conditions, the most dangerous

concentrations of fallout particles (i.e., potentially fatal to those outside) occur within 20 miles downwind of the event and are expected to be clearly visible as they fall, possibly resembling sand, table salt,<sup>26</sup> ash<sup>27</sup>, or rain.

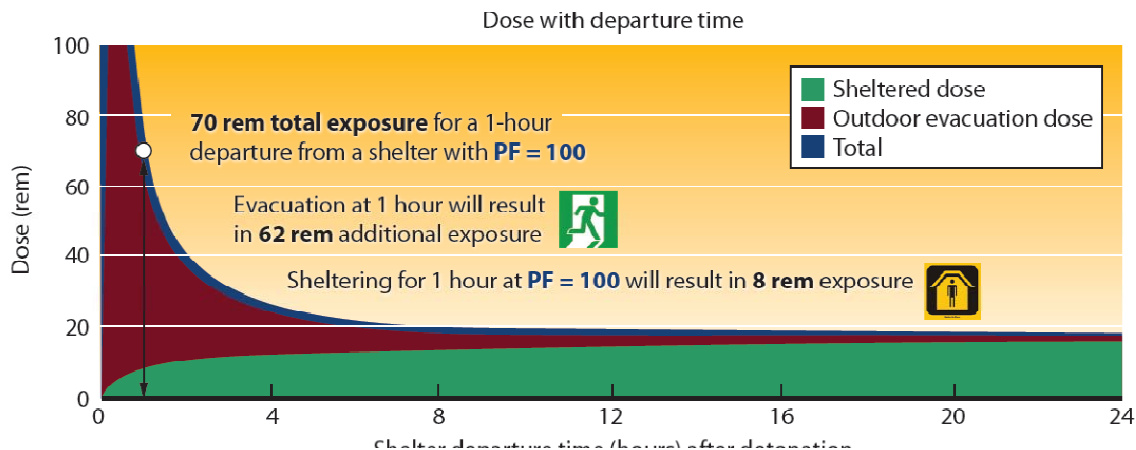


**Figure 8: Potential Dose Rates 1.6 miles downwind of a 10kT detonation (weather dependant)**

Although the lowest possible evacuation exposure can be achieved through delayed departure, that delay also means that individuals are also receiving exposure from fallout while waiting in their shelter. Evaluation of the total exposure for different lengths of sheltering periods was performed by summing the cumulative exposure received while sheltered with the exposure received during evacuation to determine the total dose received by an individual for a particular evacuation strategy.

A way to display this information is in a cumulative dose graph shown in Figure 9, which demonstrates the total exposure (shelter dose + evacuation dose) with various shelter departure times. This analysis uses the outdoor exposure rates noted in Figure 8 and a shelter protection of PF=100, which can be found in the core of office buildings like the one displayed in Figure 6.

In this example, the one-hour departure will result in cumulated shelter dose of 8 rem and an evacuation dose of 62 rem, yielding a total exposure of 70 rem for an evacuation at 1 hour. Notice that the longer sheltering results in a lower total dose, and that a 24-hour departure can result in a total dose of 17 rem, significantly less than the one-hour departure dose of 70 rem. Through the use of this graph, the total (shelter + evacuation) dose can be determined for any of the shelter departure times noted on the figure.



**Figure 9: Cumulative dose for various shelter departure times**

More detail on the methodology of this analysis can be found in *Key Response Planning Factors for the Aftermath of Nuclear Terrorism*<sup>25</sup>

## COMMUNITY OUTREACH

If a nuclear detonation were to occur in a modern US city, the greatest reduction of casualties is achieved through actions taken by citizens themselves and their state and local officials. The most critical decisions are those made in the first few minutes. Unfortunately many consider such an event to be so catastrophic that local response planning may be useless. There is a misguided impression that there would be no responders left after the detonation or that the initial response would be a federal government responsibility. Without planning, this might be a self fulfilling prophecy with hundreds of thousands of additional potential casualties as a result.

The largest potential for reduction in casualties<sup>e</sup> during the response phase (post detonation) comes from reducing exposure to fallout radiation. This can be accomplished through early, adequate sheltering followed by informed, delayed evacuation.<sup>f</sup> The response challenges of a nuclear detonation must be solved through multiple approaches of public information, planning, and rapid response actions. Because the successful response will require extensive coordination by a large number of organizations and supplemented by appropriate responses by local responders and the general population within the hazard zones, regional planning is essential to success.

By the nature of their work, response organizations are distributed throughout a community and the vast majority of the response base would survive. However, without a basic level of large-scale emergency planning, these response organizations will not

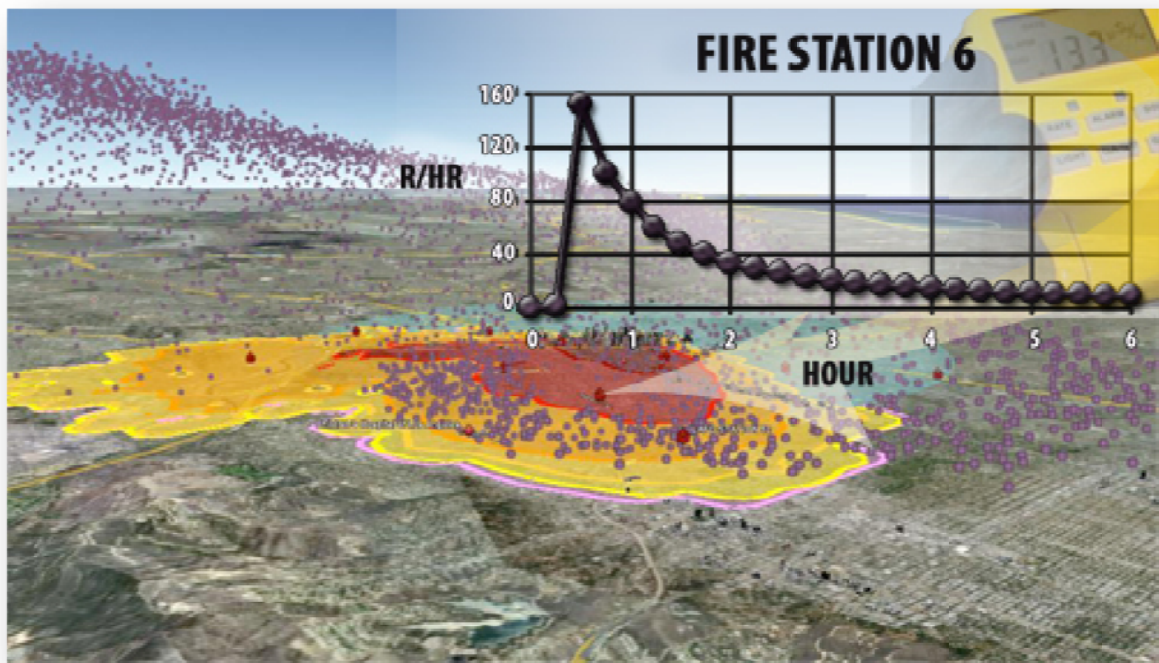
<sup>e</sup> Casualties are defined in this document as both injuries and fatalities.

<sup>f</sup> This report focuses primarily on protection from fallout. Other issues, including planning actions that would reduce injuries/fatalities arising from the prompt effects (e.g. “duck and cover” to reduce broken glass injuries) are only briefly discussed.

know how to apply their skills safely and effectively. Although considerable federal capabilities exist, it is unlikely that comprehensive assets would arrive in the first few days and may be further delayed by national actions to prevent or mitigate further attacks.

The results of initial DHS modeling and analysis were presented to federal, state, and local working groups to obtain critical, broad-based review and feedback on strategy and messaging. This effort involved a diverse set of communities, including New York City, The National Capitol Region, Charlotte, Houston, Portland, and Los Angeles.

In addition to some of the technical information noted above, advanced modeling, animation, and graphics were used to help convey how a nuclear detonation event in the city of the community of interest might unfold. Animation of cloud movement (as seen from the perspective of someone on the ground), the visualization of rapidly changing affected areas as the fallout accumulates and then decays, and the efficacy of various shelter / evacuation strategies were all presented to emergency responders, emergency managers, and public health officials.



**Figure 10: New visualization tools for fallout cloud movement and decay are used for community outreach**

This updated information and methods of communication have been very well received by the response planning community and has helped overcome the inaccurate impression that local response planning is futile. Regional planning efforts for response to nuclear terrorism are being initiated in several communities.

## NATIONAL GUIDANCE

Until recently, response planners faced a lack of federal guidance and scientific consensus on the correct actions to take. The 2006 Federal Register Notice published by the Department of Homeland Security<sup>28</sup>, which clarified how existing protective action guidance can be applied for radiological and nuclear terrorism, did not specifically address guidance for the acute effects of a domestic nuclear explosion<sup>29</sup>.

Now, in addition to the technical reports discussed above, a federal interagency effort has developed the *National Planning Guidance for Response to a Nuclear Detonation*<sup>30</sup> in January of 2009 (a 2010 update is currently under review) and work by the National Council of Radiation Protection and Measurement on *Responding To Radiological And Nuclear Terrorism: A Guide For Decision Makers* is expected to be published in the Spring of 2010.

In addition to the nuclear terrorism specific guidance, the Department of Homeland Security has extensive preparedness activities, including preparedness grants to states and urban areas totaling billions of dollars. The Department's preparedness programs and strategies favor a capability development approach that stresses mitigating the effects of a variety of events. In this regard, preparedness for the low yield nuclear detonation scenario will create important capabilities for a number of catastrophic events that require:

- coordinated regional response,
- time critical decision making,
- mass casualty response,
- crisis communication, and
- resource prioritization.

The Department of Homeland Security's National Preparedness Guidance<sup>31</sup> states; "Because major events will undoubtedly have a regional impact, there is no greater necessity than to collaborate on a regional basis to leverage expertise, share specialized assets, enhance capacity, and interoperate cohesively and effectively." Few scenarios engage regional response planning better than a low yield nuclear detonation.

Since so many lives depend on actions taken by citizens and responders in the first few hours, the capability to make decisions and disseminate guidance quickly is essential for a large number of rapidly unfolding catastrophic events. A process must be in place to avoid the paralysis that can occur in the initial phases of an event when immediate action needs to be taken and uncertainty about the nature of the event is high.

## Conclusion

Recent research indicates that many potentially lethal effects of a nuclear detonation are greatly mitigated by the urban environment. The ranges of prompt thermal and ionizing radiation effects are significantly reduced by urban shadowing and shielding. Fallout

continues to be a significant issue, but adequate shelter is easily found in the urban environment.

If a nuclear detonation were to occur in a modern US city, the greatest reduction of casualties can be achieved through rapid actions taken by citizens supported by information and prompt actions by their state and local officials. Unfortunately most response organizations (and the general public) currently lack fundamental awareness and planning to make informed decisions following a nuclear event. This planning is needed due to both the short time available for critical decisions and the extensive area impacted.

Given a daytime population density of a large modern city, the number of people who could be hurt by prompt effects or threatened by fallout could easily be in the hundreds of thousands. Fortunately, the number of casualties can be significantly reduced by taking appropriate response actions and community pre-event planning at the local level. The largest potential for reduction in casualties comes from reducing exposure fallout radiation which is accomplished through early, adequate sheltering followed by informed, delayed evacuation. A well organized response will enable sheltered populations perform informed evacuations and support timely medical intervention which would greatly improve the prognosis of the injured<sup>32 33 34 35 36 37 38 39 40</sup>.

Recent developments in scientific understanding, federal guidance, and preparedness tools have formed a foundation for state and local planning. Resources are available for state and local regional catastrophic response planning that can be used to help bring a region together to address a number of difficult challenges presented by the nuclear terrorism scenario. The capabilities gained through this process can facilitate an effective response to a variety of natural and manmade catastrophic events involving large-scale incident response coordination, mass casualty, mass evacuation, and mass care.

---

<sup>1</sup> Conference Report for the U.S. Troop Readiness, Veterans' Care, Katrina Recovery, and Iraq Accountability Act (P.L. 110-28)

<sup>2</sup> National Academy of Sciences, 2005, Nuclear Attack, factsheet created for News and Terrorism: Communicating in a Crisis.

<sup>3</sup> Federation of American Scientists, 2006, Analysis of Ready.gov. Available online: <http://www.fas.org/reallyready/analysis.html>.

<sup>4</sup> Davis, L., LaTourrette, T., Mosher, D.E., Dais, L.M., & Howell, D.R., 2003, Individual Preparedness and Response to Chemical, Radiological, Nuclear, and Biological Terrorist Attacks [Electronic version]. Arlington, Virginia: RAND Corporation.

<sup>5</sup> Orient, J., May 2005, Unready.gov. Civil Defense Perspectives, 21(4). Retrieved June 23, 2006, from <http://www.oism.org/cdp/may2005.html>.

<sup>6</sup> Department of Homeland Security (DHS), Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents issued in the Federal Register (Vol. 73, No. 149, pp 45029 – 45049), August 1, 2008.

<sup>7</sup> Comments made by Chicago responder Joseph Newton at the August 8<sup>th</sup> 2006 National Academy of Sciences, Institute of Medicine workshop entitled: Assessing Medical Preparedness for a Nuclear Event.

<sup>8</sup> R. E. Marrs, W. C. Moss, B. Whitlock, Thermal Radiation from Nuclear Detonations in Urban Environments, Lawrence Livermore National Laboratory, June 7, 2007. UCRL-TR-231593. For recent updates on this work contact Brooke Buddemeier at [brooke2@llnl.gov](mailto:brooke2@llnl.gov)

<sup>9</sup> Mlakar, Sr., P.F., W.G. Corley, M.A. Sozen, & C.H. Thornton, August 1998, "The Oklahoma City Bombing: Analysis of Blast Damage to the Murrah Building". Journal of Performance of Constructed Facilities 12(3): pp. 113-119.

- 
- <sup>10</sup> Akizuki, T., 1981, Nagasaki, 1945. Quartet Books, London, UK.
- <sup>11</sup> Safety Solutions, Posted: 15 October 2005, "Preventing glass from becoming a lethal weapon." [www.safetysolutions.net.au](http://www.safetysolutions.net.au), Retrieved on November 1, 2007.
- <sup>12</sup> Applied Research Associates, Inc., 2004, Injury based glass hazard assessment: range-to-effect curves, Sponsored by US Army Technical Center for Explosives Safety, DACA45-02-D-0004.
- <sup>13</sup> Glasstone, S. and Dolan, P.J., 1977, The Effects of Nuclear Weapons (third edition). Washington, D.C.: U.S. Government Printing Office, Available online (PDF).
- <sup>14</sup> NATO, 1996, NATO Handbook on the Medical Aspects of NBC Defensive Operations (Part I - Nuclear). Departments of the Army, Navy, and Air Force: Washington, D.C.
- <sup>15</sup> Ocular Injuries Sustained by Survivors of the Oklahoma City Bombing, American Academy of Ophthalmology ISSN 0161-6420
- <sup>16</sup> Johnson, J.O., et. al., "Assessment of Building Protection Factors For Fallout Radiation Due To An IND Urban Detonation," Oak Ridge National Laboratory, April 2010. For more information contact the author at [johnsonjo@ornl.gov](mailto:johnsonjo@ornl.gov).
- <sup>17</sup> Brandt, L.D., Yoshimura, A.S., Analysis of Sheltering and Evacuation Strategies for an Urban Nuclear Detonation Scenario, Sandia National Laboratories, SAND2009-3299, June 2009. For more information Email: [lbrandt@sandia.gov](mailto:lbrandt@sandia.gov).
- <sup>18</sup> Brandt, L.D., Mitigation of Nuclear Fallout Risks Through Sheltering and Evacuation, Sandia National Laboratories, SAND2009-7367C, November 18, 2009, for more information Email: [lbrandt@sandia.gov](mailto:lbrandt@sandia.gov).
- <sup>19</sup> Brandt, L.D., Yoshimura, A.S., NUClear EVacuation Analysis Code (NUEVAC): A Tool for Evaluation of Sheltering and Evacuation Responses Following Urban Nuclear Detonations, Sandia National Laboratories, SAND2009-7507, November 2009. For more information Email: [lbrandt@sandia.gov](mailto:lbrandt@sandia.gov).
- <sup>20</sup> Peterson, K.R., Shapiro, C.S., Internal Dose Following a Major Nuclear War, Health Phys. 62(1):29-40; 1992
- <sup>21</sup> Levanon, I.; Pernick, A. The inhalation hazard of radioactive fallout. Health Phys. 54:645-657; 1988
- <sup>22</sup> Crocker, G.R., O'Connor, J.D., Freiling, E.C., Physical and Radiochemical Properties Of Fallout Particles, Health Phys. 12: 1099-1104, 1966. \*
- <sup>23</sup> Lacy, W.J., Stangler, M.J., The Post Attack Water-Contamination Problem, Health Phys. Vol 8; 423427. 1962.
- <sup>24</sup> Mamuro, T., Fujita, A., Matsunami, T., Electron Microprobe Analysis of Fallout Particles., Health Phys. Vol. 13, pp. 197-204 (1967)
- <sup>25</sup> Buddemeier, B.R., Dillon, M.B., Key Response Planning Factors for the Aftermath of Nuclear Terrorism, Lawrence Livermore National Laboratory, LLNL-TR-410067, August 2009. For more information contact [brooke2@llnl.gov](mailto:brooke2@llnl.gov).
- <sup>26</sup> National Council on Radiation Protection and Measurements, 1982, The Control of Exposure of the Public to Ionizing Radiation in the Event of Accident or Attack. NCRP Symposium proceedings (Session B, Topic 4).
- <sup>27</sup> Lessard, E.T., et al, Thyroid absorbed Dose for People At Rongelap, Utirik and Sifo On March 1, 1954, Brookhaven National Laboratory, BNL51882, UC-48, Biology and Medicine TIC-4500,
- <sup>28</sup> Federal Register, Jan. 3, 2006, Part II Department of Homeland Security: Preparedness Directorate; Protective Action Guides for Radiological Dispersion Device (RDD) and Improvised Nuclear Device (IND) Incidents. Vol. 71, No. 1, pg. 184.
- <sup>29</sup> MacKinney, J., 2006, Protective Action and Remediation Guidance Following Radiological Dispersal Device or Improvised Nuclear Device Attacks, 1st Joint Emergency Preparedness and Response/Robotic and Remote Systems Topical Meeting of the American Nuclear Society.
- <sup>30</sup> Homeland Security Council Interagency Policy Coordination subcommittee for Preparedness & Response to Radiological and Nuclear Threats, Planning Guidance for Response to a Nuclear Detonation, Office of Science and Technology Policy, Executive Office of the President ([www.ostp.gov](http://www.ostp.gov)), January 16, 2009.
- <sup>31</sup> Department of Homeland Security, 2005, National Preparedness Guidance, Available online: <http://www.ojp.usdoj.gov/odp/docs/NationalPreparednessGuidance.pdf>.
- <sup>32</sup> Einav, S., Z. Feigenberg, C. Weissman, D. Zaichik, G. Caspi, D. Kotler, & H. Freund, 2004, Evacuation priorities in mass casualty terror-related events: implications for contingency planning. Annals of Surgery, 239:3.

- 
- <sup>33</sup> Ellidokuz, H., R. Ucku, U. Aydin, & E. Ellidokuz, 2005, Risk factors for death and injuries in earthquake: cross sectional study from Afyon, Turkey. *Croat Medical Journal*, 46:4.
- <sup>34</sup> Macleod, J., S. Cohn, E. Johnson, & M. McKenney, 2007, Trauma deaths in the first hour: are they all unsalvageable injuries? *American Journal of Surgery*, 193:2.
- <sup>35</sup> Noland, R. & M. Quddas, 2004, Improvements in medical care and technology and reductions in traffic related fatalities in Great Britain. *Accident Analysis and Prevention*, 36.
- <sup>36</sup> Sampalis, J. A. Lavoie, J. Williams, D. Mulder, & M. Kalina, 1993, Impact of on-site care, prehospital time, and level of in-hospital care on survival in severely injured patients. *The Journal of Trauma*, 34:2.
- <sup>37</sup> Teague, D., 2004, Mass casualties in the Oklahoma City bombing. *Clinical Orthopedics and Related Research*, 422.
- <sup>38</sup> Trunkey, D., 1983, Trauma. *Scientific American*, 249:2.
- <sup>39</sup> Wightman, J. & S.L. Gladish, 2001, Explosions and Blast Injuries. *Annals of Emergency Medicine*, 37(6), pp. 664-678.
- <sup>40</sup> Wyatt, J., D. Beard, A. Gray, A. Busuttil, & C. Robertson, 1995, The time of death after trauma. *BMJ*, 310.

Prepared by LLNL under Contract DE-AC52-07NA27344.